



(19)

Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 772 222 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.05.1997 Bulletin 1997/19

(51) Int. Cl.⁶: **H01J 37/32**

(21) Application number: **96117351.5**

(22) Date of filing: **29.10.1996**

(84) Designated Contracting States:
DE FR GB IT NL

(30) Priority: **01.11.1995 JP 285083/95**

(71) Applicant: **CANON KABUSHIKI KAISHA**
Tokyo (JP)

(72) Inventor: **Suzuki, Nobumasa**
Ohta-ku, Tokyo (JP)

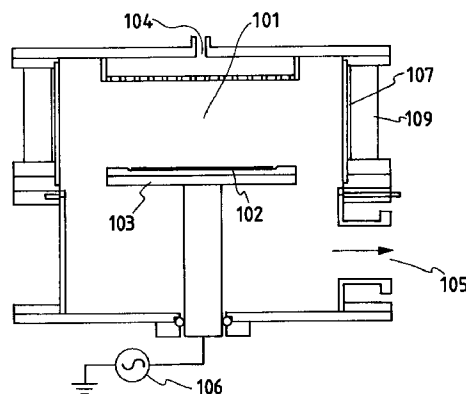
(74) Representative: **Tiedtke, Harro, Dipl.-Ing.**
Patentanwaltsbüro
Tiedtke-Bühling-Kinne & Partner
Bavariaring 4
80336 München (DE)

(54) Microwave plasma process apparatus and microwave plasma process method

(57) A plasma process apparatus comprises a plasma process chamber (101), substrate-to-be-processed supporting means (103) for supporting a substrate (102) to be processed, provided in the process chamber, gas introducing means (104), gas evacuation means (105), microwave introducing means using an endless circular waveguide (109) having a plurality of slots arranged around the process chamber, and radio frequency power supplying means (106) for supplying radio frequency power to the substrate supporting means.

The above arrangement permits a uniform plasma to be generated in high density and in a large area even under the low-pressure condition of about 1 mTorr without using a magnetic field, thus enabling etching of large-area substrates in super fine patterns and at high speed.

FIG. 1A



EP 0 772 222 A1

Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a microwave plasma process apparatus. The apparatus enables etching of large-area substrates in super fine patterns at high speed. Further, the apparatus can be applied to oxidation, nitriding, doping, cleaning, cleaning ashing, and so on.

Related Background Art

The reactive ion etching (RIE) apparatus for applying RF (radio frequency) power between parallel plate electrodes opposed to each other is frequently used for pattern formation in fabrication of electronic components such as ultra-large-scale integrated (ULSI) circuits.

A conventional RIE apparatus is shown in Fig. 2. In a process chamber 201 there are provided a holder 203 for a substrate 202 to be processed, and a gas introducing means 204. An RF power supply 206 is connected to the holder 203. The process chamber is evacuated by an evacuation means 205.

Etching is carried out as follows. The inside of the process chamber 201 is evacuated to a vacuum through the evacuation means 205. Subsequently, etching gas is introduced at a predetermined flow rate through the gas introducing means 204 into the process chamber. Then a conductance valve (not shown) set in the evacuation means 205 is adjusted to keep the inside of the process chamber 201 at a predetermined pressure. Desired power is supplied from the RF power supply 206 to the substrate holder 203. Electrons are accelerated by an RF electric field to generate a plasma in the process chamber 201. The plasma ionizes the etching gas, and ions produced thereby are accelerated by a self-bias electric field formed near the substrate 202 to impinge upon the surface of the substrate, thereby etching the surface.

It is, however, not easy for the conventional RIE apparatus to achieve discharge under low pressures of about 10^{-3} Torr, under which anisotropy of ion incidence directions can be maintained, and therefore, the conventional RIE apparatus is not effective in performing anisotropic etching of fine patterns. With increase of integration of devices demand is increasing for further making the patterns finer, but the conventional apparatus fails to meet this demand.

Another etching apparatus under research, replacing the RIE apparatus, is a plasma process apparatus utilizing electron cyclotron resonance (ECR), which can achieve discharge under the low-pressure condition of about 10^{-3} Torr. The ECR is a phenomenon that in the case of the magnetic flux density of 87.5 mT, the electron cyclotron frequency of electrons rotating around

magnetic lines of force is coincident with the ordinary frequency of microwave 2.45 GHz whereby the electrons resonantly absorb the microwave to be accelerated, thereby generating a high-density plasma.

An ECR etching apparatus is shown in Fig. 3. In a process chamber 301 there are provided a holder 303 for a substrate 302 to be processed, and a gas introducing means 304. An RF power supply 306 is connected to the holder 303. The process chamber is evacuated by an evacuation means 305. Further, in the process chamber the microwave is introduced through a microwave introducing window 307 and a magnetic field can be generated by a magnetic field generating means 308.

Etching is carried out as follows. The inside of the process chamber 301 is evacuated to a vacuum through the evacuation means 305. Subsequently, the etching gas is introduced at a predetermined flow rate through the gas introducing means 304 into the process chamber 301. Then a conductance valve (not shown) set in the evacuation means 305 is adjusted to keep the inside of the process chamber 301 at a predetermined pressure. The magnetic field of 875 G is generated in the process chamber 301 by the magnetic field generating means 308 and microwave power is introduced through the microwave introducing window 307 into the process chamber 301 to generate a plasma. Electrons helically move around magnetic lines of force, and when the frequency of rotation of the electrons comes to coincide with the frequency (normally 2.45 GHz) of the microwave (in the case of the magnetic flux density 875 G), the electrons resonantly absorb the microwave to be accelerated. Further, the electrons ionize neutral molecules by bombardment, thereby forming a high-density plasma. When desired power is supplied from the RF power supply 306 to the support holder 303 at this time, the ions are accelerated by the self-bias electric field formed near the substrate 302 to impinge upon the surface of the substrate, thereby etching the surface.

Use of such ECR etching apparatus permits discharge to occur even under the low-pressure condition of about 1 mTorr, which enables anisotropic etching of fine patterns.

The ECR etching apparatus as shown in Fig. 3, however, is not easy to generate a uniform magnetic field, so that the apparatus has a problem of nonuniformity of etching and a problem of device destruction due to charge separation in a direction along the surface of the substrate. Because of high temperatures of electrons, in the case of processing of fine patterns with high aspect ratios, abnormal etching (notch) is also likely to be caused by charge separation in a direction along the depth of the substrate.

An object of the present invention is to provide a plasma process apparatus and method, solving the problems in the conventional plasma process apparatus as described above, that can generate a uniform plasma in high density and in a large area even under the low-pressure condition of about 1 mTorr without

using the magnetic field, thereby enabling etching of large-area substrates in super fine patterns and at high speed.

SUMMARY OF THE INVENTION

A plasma process apparatus according to the present invention comprises a plasma process chamber, substrate-to-be-processed supporting means disposed in the process chamber, gas introducing means, evacuation means, microwave introducing means using an endless circular waveguide having a plurality of slots arranged around the process chamber, and RF power supplying means for supplying RF power to the substrate supporting means.

This arrangement permits the uniform plasma to be generated in high density and in a large area even under the low-pressure condition of about 1 mTorr without using the magnetic field, thereby enabling etching of large-area substrates in super fine patterns and at high speed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a schematic view showing the plasma processing apparatus according to the present invention;

Fig. 1B is a schematic view showing the endless circular waveguide;

Fig. 2 is a schematic view showing the RIE apparatus as a conventional example; and

Fig. 3 is a schematic view showing the ECR etching apparatus as a conventional example.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A microwave plasma process apparatus of the present invention is shown in Fig. 1A. In a process chamber 101 there are provided a holder 103 for a substrate 102 to be processed, and a processing-gas introducing means 104. An RF power supply 106 is connected to the holder 103. The process chamber is evacuated by an evacuation means 105. Surrounding the process chamber, an endless circular multi-slot waveguide 109 is provided with intervention of a quartz tube 107.

The endless circular multi-slot waveguide 109 is shown in Fig. 1B. The microwave is guided through a microwave introducing portion 110 and is emitted through a plurality of slots 111 provided in the annular internal wall.

The process is carried out as follows. The inside of the process chamber 101 is evacuated to a vacuum through the evacuation means 105. Then the etching gas is introduced at a predetermined flow rate through the gas inlet port 104 into the process chamber 101. Next, a conductance valve (not shown) set in the evacuation means 105 is adjusted to keep the inside of the

process chamber 101 at a predetermined pressure. Desired power is supplied from a microwave power supply (not shown) through the waveguide 109 into the process chamber 101, thereby generating a plasma. When the RF power is supplied from the RF power supply 106 to the substrate holder 103 at this time, ions are accelerated by the self-bias electric field formed near the substrate 102 to impinge upon the surface of the substrate, thereby etching the surface.

By using the endless circular multi-slot waveguide provided around the process chamber and the RF power supplying means for supplying the RF power to the support holder, the uniform plasma can be generated in high density and in a large area even under the low-pressure condition of about 1 mTorr without using the magnetic field, thereby enabling etching of the large-area substrate in ultra fine patterns and at high speed.

The microwave frequency used in the microwave plasma process apparatus of the present invention may be properly selected from the range of 0.8 GHz to 20 GHz.

The shape of the waveguide used in the plasma process apparatus of the present invention may be not only cylindrical, but also of any other shape, for example, of a disk or polygon, depending upon the configuration of the process chamber.

The plasma process apparatus of the present invention may further use a magnetic field generating means in addition to the above arrangement. Desired conditions of the magnetic field are those of the cusped magnetic field which has node planes lying on planes including the centers of the plural slots in the endless circular multi-slot waveguide and has magnetic lines of force substantially normal to the substrate supporting means and in which the magnetic flux density of the magnetic field near the slots is greater than that near the substrate.

The magnetic field generating means may be either a coil or a permanent magnet. In the case of the coil being used, a water cooling mechanism or any other cooling means such as air cooling means may be used in order to prevent overheat.

The pressure in the process chamber in the plasma process method of the present invention may be selected preferably from the range of 0.2 mTorr to 10.0 mTorr.

Thin films that can be processed by the plasma etching method of the present invention include electrically insulating films of Si_3N_4 , SiO_2 , Ta_2O_5 , TiO_2 , TiN , Al_2O_3 , AlN , MgF_2 , and so on; semiconductor films of a-Si (amorphous Si), poly-Si, SiC, GaAs, and so on; metal films of Al, W, Mo, Ti, Ta, and so on, etc., and the various thin films can be etched with efficiency.

The substrate to be processed by the plasma etching method of the present invention may be either one of semiconductor substrates, electrically conductive substrates, and electrically insulating substrates.

Specific examples of the electrically conductive

substrates include metals such as Fe, Ni, Cr, Al, Mo, Au, Nb, Ta, V, Ti, Pt, and Pb; and alloys thereof, for example brass and stainless steel.

Specific examples of the electrically insulating substrates include various glasses such as SiO₂-based quartz; inorganic materials such as Si₃N₄, NaCl, KCl, LiF, CaF₂, BaF₂, Al₂O₃, AlN, and MgO; films and sheets of organic materials such as polyethylene, polyester, polycarbonate, cellulose acetate, polypropylene, polyvinyl chloride, polyvinylidene chloride, polystyrene, polyamide, and polyimide.

The etching gas used in the plasma etching method of the present invention may be selected from generally well-known gases. Specifically, depending upon the film or substrate to be etched, the etching gas may be selected from F₂, CF₄, CH₂F₂, C₂F₆, CF₂Cl₂, SF₆, and NF₃.

The plasma process apparatus and method of the present invention can also be applied to modification of surface, cleaning, resist ashing, or the like, as well as etching. For example, using Si, Al, Ti, Zn, or Ta as a substrate or surface layer, the substrate or surface layer of these can be subject to oxidation or nitriding or to doping with B, As, or P. Another application is a cleaning ashing process for removing organic materials including the resist, inorganic materials, and metal from the surface of the substrate.

For the surface process to oxidize the substrate, oxidizing gas may be selected from O₂, O₃, H₂O, NO, N₂O, and NO₂. For the surface process to nitride the substrate, nitriding gas may be selected from N₂, NH₃, N₂H₄, and hexamethyldisilazane (HMDS).

For the cleaning ashing of organic materials including the resist on the surface of the substrate, cleaning gas may be selected from O₂, O₃, H₂O, NO, N₂O, and NO₂. For the cleaning of the inorganic materials and metal on the surface of the substrate, cleaning gas may be selected from F₂, CF₄, CH₂F₂, C₂F₆, CF₂Cl₂, SF₆, and NF₃.

[Examples]

The plasma process apparatus and method of the present invention will be described more specifically with examples, but it is noted that the present invention is by no means intended to be limited to these examples.

[Example 1]

Using the plasma process apparatus shown in Fig. 1A, etching was carried out on a polysilicon film between the gate electrodes of semiconductor device.

The substrate 102 used herein was a p-type single-crystal silicon substrate (face orientation $\langle 100 \rangle$ and resistivity 10 Ωcm) with a polysilicon film formed as an uppermost layer. First, after the silicon substrate 102 was set on the substrate holder 103, the inside of the process chamber 101 was evacuated to a vacuum

through the evacuation system 105, so as to decrease the pressure down to the value of 10⁻⁶ Torr. Through the gas inlet port 104 CF₄ gas and oxygen were introduced at 300 sccm and at 20 sccm, respectively, into the process chamber 101. Then the conductance valve (not shown) set in the evacuation system 105 was adjusted to keep the inside of the process chamber 101 at 1.0 mTorr. Then the RF wave of 13.56 MHz was applied from the RF power supply 106 to the substrate holder 103, and the power of 1.5 kW was supplied from the microwave power supply of 2.45 GHz through the circular waveguide 109 into the process chamber 101. In this way the plasma was generated in the process chamber 101. The CF₄ gas and oxygen introduced through the gas inlet port 104 were excited and decomposed in the process chamber 101 to become active species. The active species were transported toward the silicon substrate 102 and the ions accelerated by the self-bias etched the polysilicon film.

After etching, evaluation was carried out as to the etching rate, etch selectivity, and etching shape. The etching shape was evaluated by observing cross sections of the etched polysilicon film by a scanning electron microscope (SEM). The results confirmed that the etching rate and etch selectivity over SiO₂ were good as 600 nm/min and 30, respectively, and that the micro-loading effect was little.

[Example 2]

Using the plasma process apparatus shown in Fig. 1A, etching was conducted on a BPSG (Boron-doped Phospho-Silicate Glass) film of semiconductor device.

The substrate 102 used herein was a p-type single-crystal silicon substrate (face orientation $\langle 100 \rangle$ and resistivity 10 Ωcm) with a BPSG film 1 μm thick formed on polysilicon pattern (lines and spaces of 0.5 μm). First, after the silicon substrate 102 was set on the substrate holder 103, the inside of the process chamber 101 was evacuated to a vacuum through the evacuation system 105, so as to decrease the pressure down to the value of 10⁻⁶ Torr. Then CF₄ was introduced at the flow rate of 300 sccm through the gas inlet port 104 into the process chamber 101. Then the conductance valve (not shown) set in the evacuation system 105 was adjusted to keep the inside of the process chamber 101 at 1.2 mTorr. Then the power of 2.0 kW was supplied from the microwave power supply of 2.45 GHz through the circular waveguide 109 into the process chamber 101. In this way the plasma was generated in the process chamber 101. The CF₄ gas introduced through the gas inlet port 104 was excited and decomposed in the process chamber 101 to become an active species. The active species was transported toward the silicon substrate 102 to etch the BPSG film.

After etching, evaluation was carried out as to the etching rate, etch selectivity, and etching shape. The etching shape was evaluated by observing cross sections of the etched BPSG film by the scanning electron

microscope (SEM). The results confirmed that the etching rate and etch selectivity over polysilicon were good as 300 nm/min and 30, respectively, that the etching shape was almost vertical, and that the microloading effect was little.

[Example 3]

Using the plasma process apparatus shown in Fig. 1A, etching was effected on an Al film of multilayer wiring of semiconductor device.

The substrate 102 used herein was a p-type single-crystal silicon substrate (face orientation (100) and resistivity 10 Ω cm) with an Al film formed as an uppermost layer. First, after the silicon substrate 102 was set on the substrate holder 103, the inside of the process chamber 101 was evacuated to a vacuum through the evacuation system 105, so as to decrease the pressure down to the value of 10^{-6} Torr. Then Cl_2 gas and gasified BCl_3 were introduced at 120 sccm and at 80 sccm, respectively, through the gas inlet port 104 into the process chamber 101. Then the conductance valve (not shown) set in the evacuation system 105 was adjusted to keep the inside of the process chamber 101 at 0.8 mTorr. Then the RF wave of 13.56 MHz was applied from the RF applying means 106 to the substrate holder 103 and the power of 1.2 kW was supplied from the microwave power supply of 2.45 GHz through the circular waveguide 109 into the process chamber 101. In this way the plasma was generated in the process chamber 101. The Cl_2 gas and BCl_3 introduced through the gas inlet port 104 were excited and decomposed in the process chamber 101 to become active species. The active species were transported toward the silicon substrate 102, so that the ions accelerated by the self-bias etched the Al film.

After etching, evaluation was carried out as to the etching rate, etch selectivity, and etching shape. The etching shape was evaluated by observing cross sections of the etched Al film by the scanning electron microscope (SEM). The results confirmed that the etching rate and etch selectivity over SiO_2 were good as 500 nm/min and 20, respectively, that the etching shape was vertical, and that the microloading effect was little.

[Example 4]

Using the plasma process apparatus shown in Fig. 1A, etching was effected on an Al film of wiring of liquid crystal display element.

The substrate 102 used herein was a blue plate glass substrate of 450 mm $\times$ 550 mm with an Al film formed as an uppermost layer. First, after the glass substrate 102 was set on the substrate holder 103, the inside of the process chamber 101 was evacuated to a vacuum through the evacuation system 105, so as to decrease the pressure down to the value of 10^{-6} Torr. Then Cl_2 gas was introduced at the flow rate of 200 sccm through the gas inlet port 104 into the process

chamber 101. Then the conductance valve (not shown) set in the evacuation system 105 was adjusted to keep the inside of the process chamber 101 at 2.0 mTorr. Then the RF wave of 13.56 MHz was applied from the RF applying means 106 to the substrate holder 103 and the power of 2.0 kW was supplied from the microwave power supply of 2.45 GHz through the circular waveguide 109 into the process chamber 101. In this way the plasma was generated in the process chamber 101. The Cl_2 gas introduced through the gas inlet port 104 was excited and decomposed in the process chamber 101 to become an active species. The active species was transported toward the glass substrate 102, so that the ions accelerated by the self-bias etched the Al film.

After etching, evaluation was carried out as to the etching rate, etch selectivity, and etching shape. The etching shape was evaluated by observing cross sections of the etched Al film by the scanning electron microscope (SEM). The results confirmed that the etching rate and etch selectivity over SiO_2 were good as 500 nm/min and 25, respectively, and that the etching shape was vertical.

[Example 5]

Using the plasma process apparatus shown in Fig. 1A, etching was carried out on a glass substrate for phase grating filter of copier optical system.

The substrate 102 used herein was a white plate glass substrate. First, after the glass substrate 102 was set on the substrate holder 103, the inside of the process chamber 101 was evacuated to a vacuum through the evacuation system 105, so as to decrease the pressure down to the value of 10^{-6} Torr. Then CF_4 and H_2 were introduced at 200 sccm and at 40 sccm, respectively, through the gas inlet port 104 into the process chamber 101. Then the conductance valve (not shown) set in the evacuation system 105 was adjusted to keep the inside of the process chamber 101 at 1.2 mTorr. Then the RF wave of 13.56 MHz was applied from the RF applying means 106 to the substrate holder 103 and the power of 2.2 kW was supplied from the microwave power supply of 2.45 GHz through the circular waveguide 109 into the process chamber 101. In this way the plasma was generated in the process chamber 101. The CF_4 gas and H_2 introduced through the gas inlet port 104 were excited and decomposed in the process chamber 101 to become active species. The active species were transported toward the glass substrate 102, so that the ions accelerated by the self-bias etched the glass substrate.

After etching, evaluation was carried out as to the etching rate and etching shape. The etching shape was evaluated by observing cross sections of the etched glass substrate by the scanning electron microscope (SEM). The results confirmed that the etching rate was good as 450 nm/min and that the etching shape was vertical.

A plasma process apparatus comprises a plasma process chamber, substrate-to-be-processed supporting means for supporting a substrate to be processed, provided in the process chamber, gas introducing means, gas evacuation means, microwave introducing means using an endless circular waveguide having a plurality of slots arranged around the process chamber, and radio frequency power supplying means for supplying radio frequency power to the substrate supporting means.

The above arrangement permits a uniform plasma to be generated in high density and in a large area even under the low-pressure condition of about 1 mTorr without using a magnetic field, thus enabling etching of large-area substrates in super fine patterns and at high speed.

Claims

1. A microwave plasma process apparatus comprising a plasma process chamber, substrate-to-be-processed supporting means for supporting a substrate to be processed, provided in said plasma process chamber, gas introducing means, evacuation means, microwave introducing means using an endless circular waveguide having a plurality of slots arranged around said plasma process chamber, and radio frequency power supplying means for supplying radio frequency power to said substrate-to-be-processed supporting means.
2. The microwave plasma process apparatus according to Claim 1, further comprising magnetic field generating means for generating a magnetic field.
3. The microwave plasma process apparatus according to Claim 2, wherein said magnetic field is substantially normal to said substrate to be processed.
4. A microwave plasma process method comprising a step of setting a substrate to be processed on substrate supporting means in a plasma process chamber, a step of evacuating the inside of said plasma process chamber, a step of introducing a gas into said plasma process chamber and keeping the inside of said plasma process chamber at a predetermined pressure, and a step of introducing a microwave through an endless circular waveguide provided around said plasma process chamber to generate a plasma therein and supplying radio frequency power from radio frequency power supplying means to said substrate supporting means.
5. The microwave plasma process method according to Claim 4, wherein the plasma process is etching.
6. The microwave plasma process method according to Claim 4, wherein the plasma process is one selected from the group consisting of an oxidation process, a nitriding process, a doping process, cleaning, and cleaning ashing.
7. The microwave plasma process method according to Claim 5, wherein said gas is an etching processing gas selected from the group consisting of F_2 , CF_4 , CH_2F_2 , C_2F_6 , CF_2Cl_2 , SF_6 , and NF_3 .
8. The microwave plasma process method according to Claim 6, wherein said gas is an oxidation processing gas selected from the group consisting of O_2 , O_3 , H_2O , NO , N_2O , and NO_2 .
9. The microwave plasma process method according to Claim 6, wherein said gas is a nitriding processing gas selected from the group consisting of N_2 , NH_3 , N_2H_4 , and hexamethyldisilazane (HMDS).
10. The microwave plasma process method according to Claim 6, wherein said gas is a cleaning gas selected from the group consisting of O_2 , O_3 , H_2O , NO , N_2O , NO_2 , F_2 , CF_4 , CH_2F_2 , C_2F_6 , CF_2Cl_2 , SF_6 , and NF_3 .

FIG. 1A

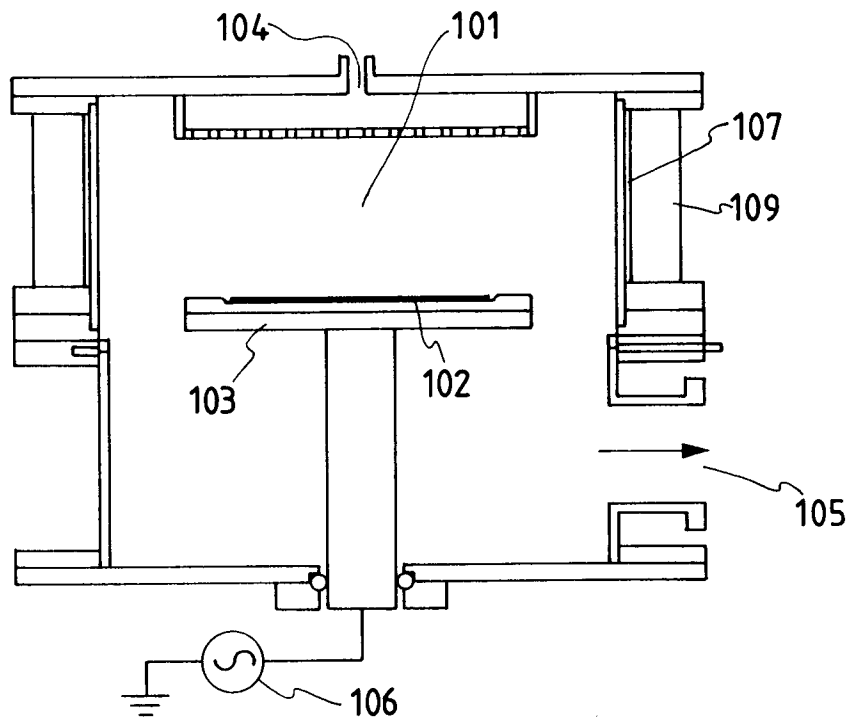


FIG. 1B

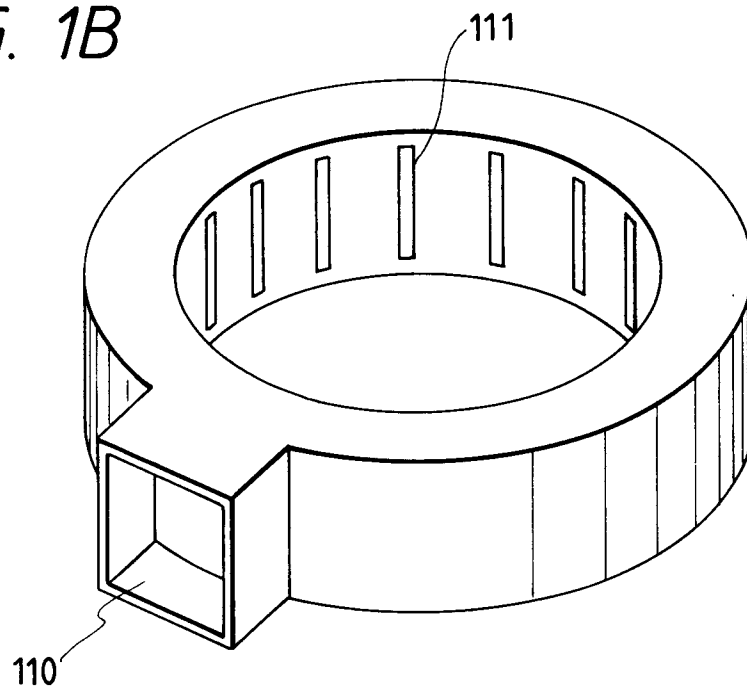


FIG. 2 PRIOR ART

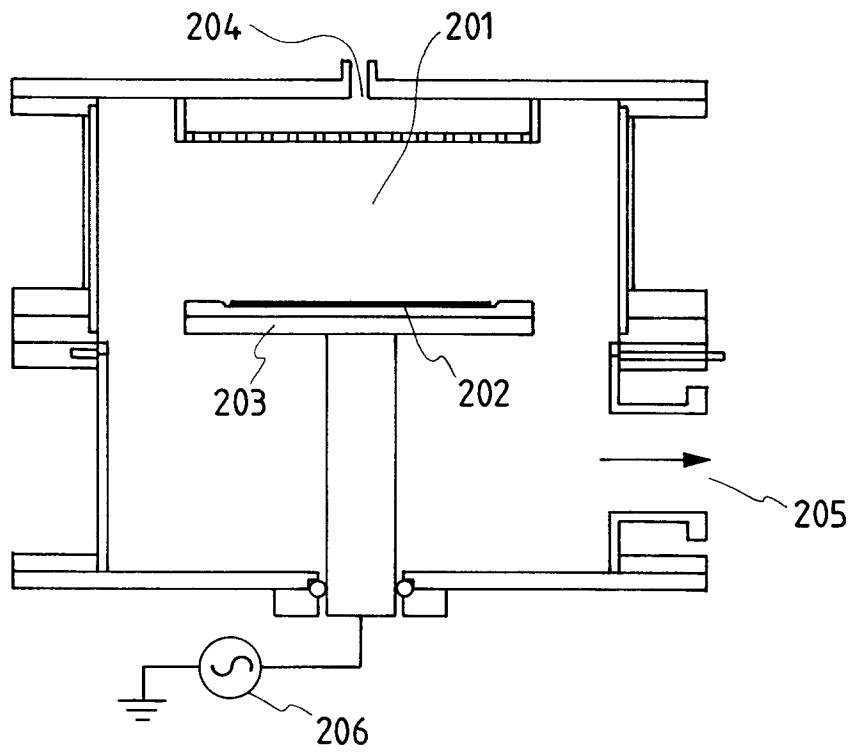
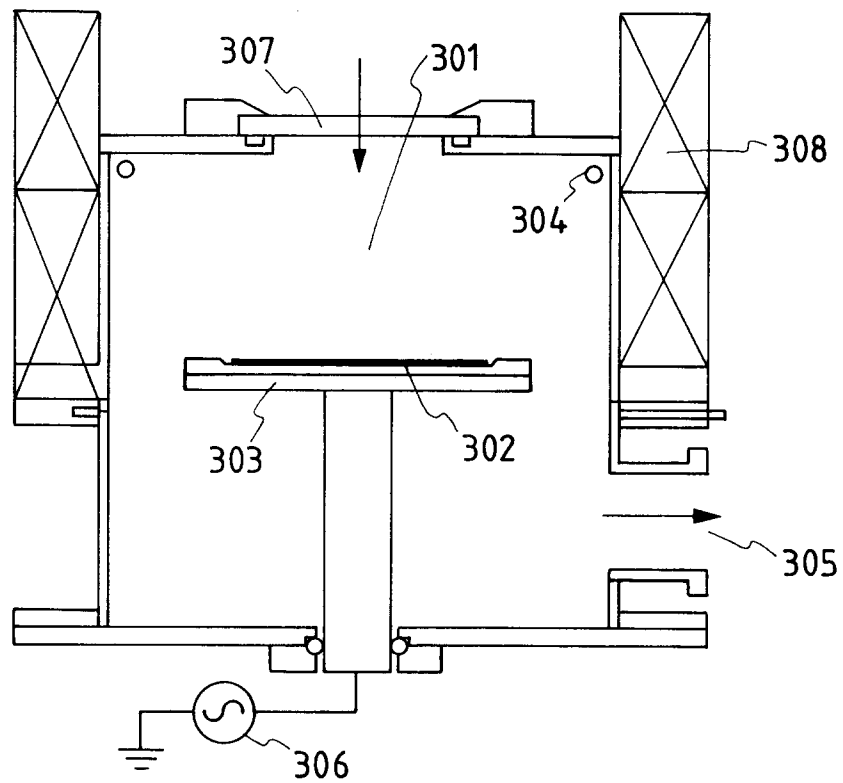


FIG. 3 PRIOR ART





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 11 7351

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	US 5 366 586 A (SAMUKAWA SEIJI) 22 November 1994 * column 3, line 15 - column 4, line 6; figure 6 *	1-5	H01J37/32
Y	EP 0 593 931 A (ENGEMANN JUERGEN PROF DR ING) 27 April 1994 * column 3, line 8 - column 4, line 28; figure 1 *	1-5	
A	PATENT ABSTRACTS OF JAPAN vol. 018, no. 191 (C-1186), 4 April 1994 & JP 05 345982 A (CANON INC), 27 December 1993, * abstract *	1,4	
A	EP 0 047 663 A (HITACHI LTD) 17 March 1982 * the whole document *	1,4-8	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01J
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		7 February 1997	Schaub, G
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 01.82 (P04C01)